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THEORECTICAL STUDY OF PULSE COMPRESSING USING NONLINEAR BIREFRINGENT FIBER WITH THIRD-ORDER DISPERSION COEFFICIENT

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ABSTRACT

We present the analytical study of using polarizer at the end of nonlinear birefringent fiber to achieve the signal pulse reshape. In this paper, stemming from the coupled nonlinear Schrödinger equation, we use the variational approach (VA) to study the factors which influence the signal pulse's transmission. The results from the technique indicate that the transmission of pulse relies on the instantaneous intensity, the third-order dispersion coefficient and the initial energy of pulse as well as the angle between the fiber's principle axe and the polarizer. It has been noticed that, choosing a proper the initial energy of signal pulse, the angle between the polarizer as well as the fiber's principle axe, one can lead to the higher transmission of the pulse in the central part than in the tails of pulse for realization of all-optical pulse compressing and pulse reshaping.

Keywords: *Nonlinear Birefringent Fiber, Pulse Reshaping, Transmission, Third-Order Dispersion Coefficient*

1. INTRODUCTION

In the ultra-long-distance optical fiber communication systems, multiple amplification and attenuation of information-carrying light pulses result in an amplification of noise which quickly deteriorates the pulse shape, and aggrandize the Bit Error Rate, so it is important to use the technique of reshaping pulse to generate suitable form's pulses that propagate in high speed optical communication systems. Thus all-optical pulse reshaping becomes one of importance issues that is required of optical 3R regenerator for the wavelength division multiplexing (WDM)/time division multiplexing (TDM) systems, the so called 3R regeneration means a Re-amplification, Re-shaping and Re-timing of the pulses. In the recent past, many techniques of reshaping optical pulse have been researched, including fiber Bragg grating [1], nonlinear optical fibre-loop mirror (NOLM) with highly nonlinear fiber (HNF) [2], χ^2 media [3], passive micro-ring resonators [4], the semiconductor filter by changing injection current [5], spectral filtering [6, 7], a semiconductor optical amplifier adding dispersion compensating fiber in a ring cavity [8]. Obviously, the technologies of reshaping pulse have stimulated a great deal of attentions, etc.

The potential of nonlinear polarization rotate to build ultra-fast all-optical devices has received considerable attention. It has been supposed to use it for pulse shaper, optical switcher, nonlinear filiter, etc [9-11]. An alternative approach to remove the pedestals or reshape the pulses is using polarizer at the fiber end to exploit the nonlinear birefringence induced by the optical Kerr effect. Birefringent fibers can be formed by twisting the fiber performs; the fibers can also be made by stress-induced birefringent mechanisms. Recent theoretical and experimental research has completed on intensity dependent change in twisted optical fibers [12-18].When the pulse propagates through a combination of birefringent fiber and polarizer, the transmission of the device depends on the instantaneous intensity of the incident optical wave. By adjusting the initialization intensity of the incident optical pulse and the angle between polarizer and the fiber's principal axes, one can let the device to attenuate and resist the lower intensity of the optical pulse, but allow the transmission of the portion of higher intensity of optical pulse to pass. Thus the pedestal of optical pulse is removed in order to reshape the pulses.

In this paper, we research reshaping pulse by nonlinear birefringence. Pulse reshaping by nonlinear birefringence has been studied before [19], to the best of our knowledge, but never in the context of considering linear coupling which is introduced by an intensity-dependent coupling between the fiber's principal axes and third-order dispersion effecting, as well as considering third order dispersion for ultra-short pulse. The objective of this paper is to determine how to select a proper polarization angle, third-order dispersion coefficient and initial energy of incident pulse in order to achieve reshaping pulse.

This paper is organized as follows. In section 2 we use the coupled nonlinear Schrödinger equations (CNLSEs) [20-22] to describe pulse propagation in a fiber with Kerr nonlinearity. In section 3, we convert the CNLSEs into a variational problem [23] with corresponding Lagrangian equations of motion for a finite number of degrees of freedom and obtain the transmission. Section 4 is devoted to a discussion of the result about the analytical calculation. The conclusion is drawn in section 5.

2. THEORETICAL MODE

The input to the ANN is the value of exponent of reactive power load-voltage characteristic (n_q) and the output is the desired proportional gain (K_P) and integral gain (K_I) parameters of the SVC. Normalized values of n_q are fed as the input to the ANN the normalized values of outputs are converted into the actual value. The process of

For the linearly polarized coupled pulses propagating in a birefringence fiber, the Schrödinger equations (CNLSEs) describing pulse are

$$i\frac{\partial u_1}{\partial \xi}+\frac{1}{2}\frac{\partial^2 u_1}{\partial \tau^2}-i\mu\frac{\partial^3 u_1}{\partial \tau^3}+k_1 u_1$$
$$+(|u_1|^2+\frac{2}{3}|u_2|^2)u_1+k_0 u_2+\frac{1}{3}u_2{}^2 u_1{}^*=0$$

（1a）

$$i\frac{\partial u_2}{\partial \xi}+\frac{1}{2}\frac{\partial^2 u_2}{\partial \tau^2}-i\mu\frac{\partial^3 u_2}{\partial \tau^3}-k_1 u_2+$$
$$(|u_2|^2+\frac{2}{3}|u_1|^2)u_2+k_0 u_1+\frac{1}{3}u_1{}^2 u_2{}^*=0$$

（1b）

Where $k_0=K_0 L_D, k_1=K_1 L_D$, $\mu=\beta_3/6|\beta_2|T_0$ are the normalized linear coupling coefficient , normalized birefringence coefficient and normalized third-order dispersion coefficient. Here $L_D=T_0^2/|\beta_2|$ is dispersion length, T_0 is the pulse width, β_2 is group-velocity dispersion coefficient， β_3 is third-order dispersion coefficient. Other normalized quantities is $\xi=z/L_D, \tau=T_1/T_0, u_1=(\gamma L_D)^{1/2}A_1$, $u_2=(\gamma L_D)^{1/2}A_2$, z is transmission distance, $\gamma=2\pi n_2/(\lambda_0 A_{\mathrm{eff}})$ is nonlinear coefficient, n_2 =2.6×10^{-16}cm^2/W is the nonlinear index coefficient of the fiber, A_{eff} =55μm^2 is the effective cross-sectional area, λ_0 =1.55μm is the free-space wavelength, T_1 represents the time delay.

We use a polarizer at the end of nonlinearly birefringence fiber, and denote the polarization vector by $\begin{pmatrix} u_1 \\ u_2 \end{pmatrix}$. The relation between propagating pulse and polarizer is denoted by the figure 1:

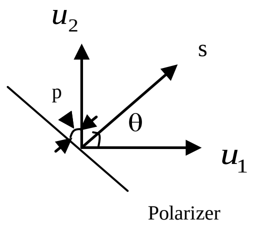

Fig. 1. Pictorial Description Of Action Of A Polarizer On A Propagating Pulse.

In figure 1 one refers to θ as the polarization angle between the fiber’s principle axe and the electrical field vector and refers to p as the angle between the other fiber’s principle axe and the polarizer.

When the pulse through a combination of fiber and polarizer, due to the change of the angle θ, an intense pulse can be used to modify the shape of the pulse.

3. VARIATIONAL ANALYSIS OF COUPLED EQUATIONS

Basing on the variation method [22], we obtain a set of differential equations that associate with the free parameters

$$\frac{\pi^2}{2}\frac{dq}{d\xi}=6\mu r^3(\frac{\pi^2}{r^3}q^2\omega-r\omega)-r^4$$

$$-\frac{1}{6}a^2\sin^2(2\theta)r^3(1-\cos 2\psi)+a^2r^3+\frac{\pi^2}{4}q^2 \quad (2a)$$

$$\frac{d\psi}{d\xi}=\frac{2}{9}a^2r\cos 2\theta(1-\cos 2\psi)-2k_0\cos\psi/\tan 2\theta+2k_1 \quad (2b)$$

$$\frac{dr}{d\xi}=-2qr-24\mu r\omega q \quad (2c)$$

$$\frac{d\theta}{d\xi}=k_0\sin\psi+\frac{1}{9}a^2r\sin 2\theta\sin 2\psi \quad (2d)$$

$$\frac{d\omega}{d\xi}=0 \quad (2e)$$

$$\frac{dc}{d\xi}=-\omega-\mu(3\omega^2+\frac{2\pi^2}{r^2}q^2+2r^2) \quad (2f)$$

Using the equation set (7) and Eqs. 5, we can restructure the optical pulse. Then we define the transmission T that the optical pulse goes through the polarizer

$$T=\frac{|u_1\sin p - u_2\cos p|^2}{|u_0|^2}$$

4. RESULTS AND DISCUSSION

In our simulation, we choose the nonlinear birefringent fiber that is 1.25km in length with nonlinear index coefficient n_2=2.6×10^{-16}cm^2/W and the group velocity dispersion coefficient β_2 =-2 ps^2/km, assume the signal pulse to be a soliton with the duration T_0 = 1ps. Then the dispersion length L_D=0.5km.

To understand the pulse reshaping by using nonlinear birefringent fiber, we solve Eqs.(2a-2f) in order to obtain the relationship of the transmission with respect with the variable normalized time. In Fig. 2 one has a plot of the transmission as a function of the normalized time τ ; Fig. 3 represents the curves of input pulse and output pulse. In this simulation, the arbitrary normalized parameters are taken as $q(0)=0$, $p(0)$=pi/3.5, k_0=0.6, k_1=0.41, μ =0.01, $\psi(0)=0$, $r(0)=1$, $\theta(0)$=pi/5, $a^2=1$. As shown in Fig. 2, the device allows that the transmission is the higher in the central (namely high intensity) part than in the edge of pulse (namely low intensity). As a result, the tails of the pulse is attenuated, but the center portion of the pulse well passes the polarizer. Fig. 3 shows that the width of output pulse is narrower than that of the input pulse. Thereby due to the output pulse becomes narrow, the aim of the pulse reshaping is achieved.

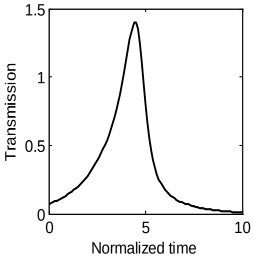

Fig. 2. Transmission Versus Normalized Time, The Figure Shows That Transmission In The Central Part Of Pulse Is Higher Than In The Tails Of Pulse With $A^2=1$

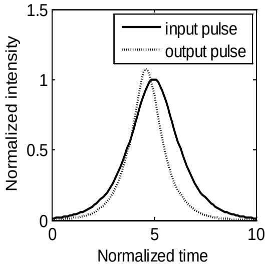

Fig. 3. The Shapes Of The Input And Output Pulse. The Figure Shows That The Output Pulse Becomes Narrow With $A^2=1$.

In Fig. 4 and 5, the corresponding normalized parameters are taken as $q(0)=0$, p=pi/3.5, k_0=0.6, k_1=0.41, $\mu=0.01$, $\psi(0)=0$, $r(0)=1$, $\theta(0)$=pi/5, a^2=0.92. In Fig. 4 it is obvious that the transmission is higher in the edge than in the central part of pulse, thus the central portion (namely high intensity portion) of the pulse is attenuated, but the tails of the pulse (namely low intensity portion) is enhanced. This is the reason why leads the optical pulse to broaden. Fig. 5 represents the shape of the input pulse and output pulse (solid line stands for the shape of the input pulse, dashed line is the shape of the output pulse).

In the above-mentioned simulations, the transmission of this pulse is different with the change of the initial energy a^2. The research demonstrates that the transmission of the pulse relies on not only the instantaneous intensity, but also the initial energy of the pulse.

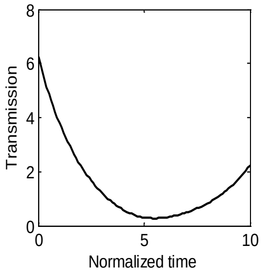

Fig. 4. Transmission Versus Normalized Time, The Figure Shows That Transmission In The Central Part Of Pulse Is Higher Than In The Tails Of Pulse With A^2=0.92.

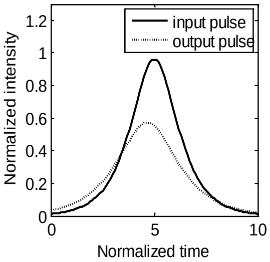

Fig. 5. The Shapes Of The Input And Output Pulse. The Figure Shows That The Output Pulse Becomes Narrow With A^2=0.92.

In Fig. 6 and 7, the corresponding normalized parameters are taken as $q(0)=0$, $p=\text{pi}/3.5$, $k_0=0.6$, $k_1=0.41$, $\mu = 0.05$, $\psi(0)=0$, $r(0)=1$, $\theta(0)=\text{pi}/5$, $a^2=0.92$. In Fig. 6 it is obvious that the transmission is higher than Fig. 2. Fig. 7 represents the shape of the input pulse and output pulse (solid line stands for the shape of the input pulse, dashed line is the shape of the output pulse). The reshaping of the pulse is better than Fig. 3.

In the above-mentioned simulations, the transmission of this pulse is different with the change of the third-order dispersion coefficient. The research demonstrates that the transmission of the pulse relies on the third-order dispersion coefficient.

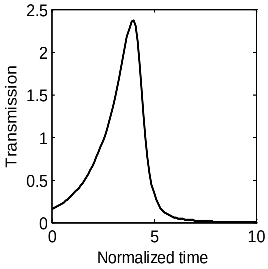

Fig. 6. Transmission Versus Normalized Time, The Figure Shows That Transmission In The Central Part Of Pulse Is Higher Than In The Tails Of Pulse With A^2=1 And $\mu = 0.05$.

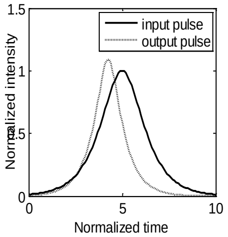

Fig. 7. The Shapes Of The Input And Output Pulse. The Figure Shows That The Output Pulse Becomes Narrow With A^2=1, $\mu = 0.05$.

Fig. 8 and 9 present the change of transmission with respect to the normalized time τ (or intensity) and the angle p between the polarizer and the fiber's principal axes at the different initial energy a^2. While a^2 is taken as 2 (other parameter: $q(0)=0$, $p(0)=\text{pi}/3.5$, $k_0=0.6$, $k_1=0.41$, $\mu=0.01$, $\psi(0)=0$, $r(0)=1$, $\theta(0)=\text{pi}/5$, $a^2=1$. As displayed in Fig. 8, the transmission in the central part of the pulse is higher than in the tails of pulse. When the angle p between the polarizer and the fiber's principal axes lies in the regime around 0 or pi, however, the transmission is very low. In Fig. 9, a^2 is taken as 0.92, the graph illuminate that the transmission in the tails of pulse is higher than the central part. So provided that selecting a proper angle p and the initial energy a^2, one can achieve that the transmission in the central part of pulse is higher than in the tails of pulse, consequently, realize the pulse to reshape. The study, furthermore, explains that the transmission of the pulse depends on the angle between the polarizer and the fiber’s principle axe besides the intensity and the initial energy of the pulse.

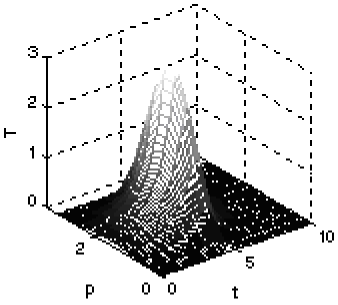

Fig. 8 Transmission Versus The Normalized Time τ And The Angle *P* Between Polarizer And Fiber's Principle Axe With Energy Factor With A^2=1.

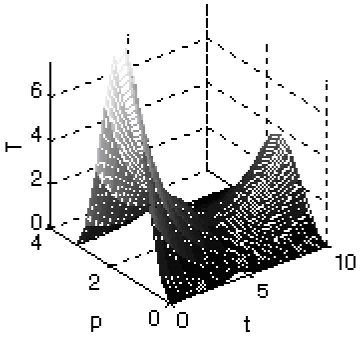

Fig. 9 Transmission Versus The Normalized Time τ And The Angle *P* Between Polarizer And Fiber's Principle Axe With Energy Factor With A^2=0.92.

Fig. 10 and 11 present the evolution of the optical pulse in the fiber's slow axe and fast axe with a=1. In the fiber's slow axis the intensity of pulse become higher when the pulse evolutes in the fiber and the intensity of pulse become lower in the fiber's fast axis. This is because of the coupling of the fiber's slow and fast axis.

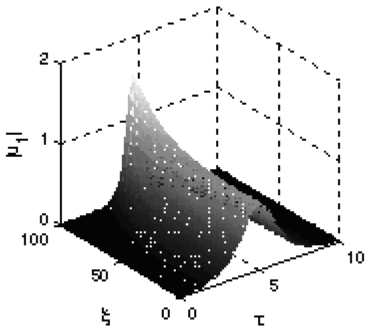

Fig. 10 Evolution Of The Optica Pulse In The Fiber's Slow Axe With A=1.

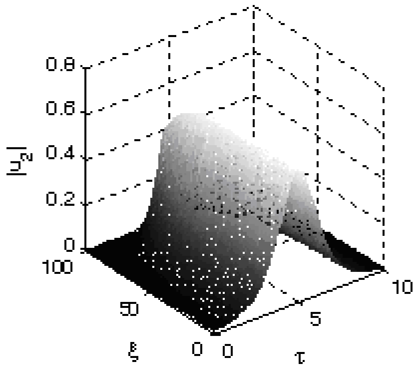

Fig. 8 Evolution Of The Optica Pulse In The Fiber's Fast Axe With *A*=1.

5. CONCLUSION

In conclusion, like the above-mentioned works, we have known that using the polarizer at the end of nonlinear birefringent fiber can perform pulse reshaping. In the paper, basing on the coupled nonlinear Schrödinger equation in the nonlinear birefringent fiber, we use the VA to study the ingredients which affect transmission of the pulse. The results confirms our main claim that， the transmission of pulse relies on the instantaneous intensity, the initial energy of pulse, and third-order dispersion coefficient as well as the angle between the fiber's principle axe and the polarizer. It has been noticed that, choosing a proper the initial energy of signal pulse , third-order dispersion coefficient and the angle between the polarizer as well as the fiber's principle axe, one can lead to the higher transmission of the pulse in the central part than in the tails of pulse, consequently, pulse compressing or pulse reshaping can be achieved.

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